Overview of Kansas Earthquakes

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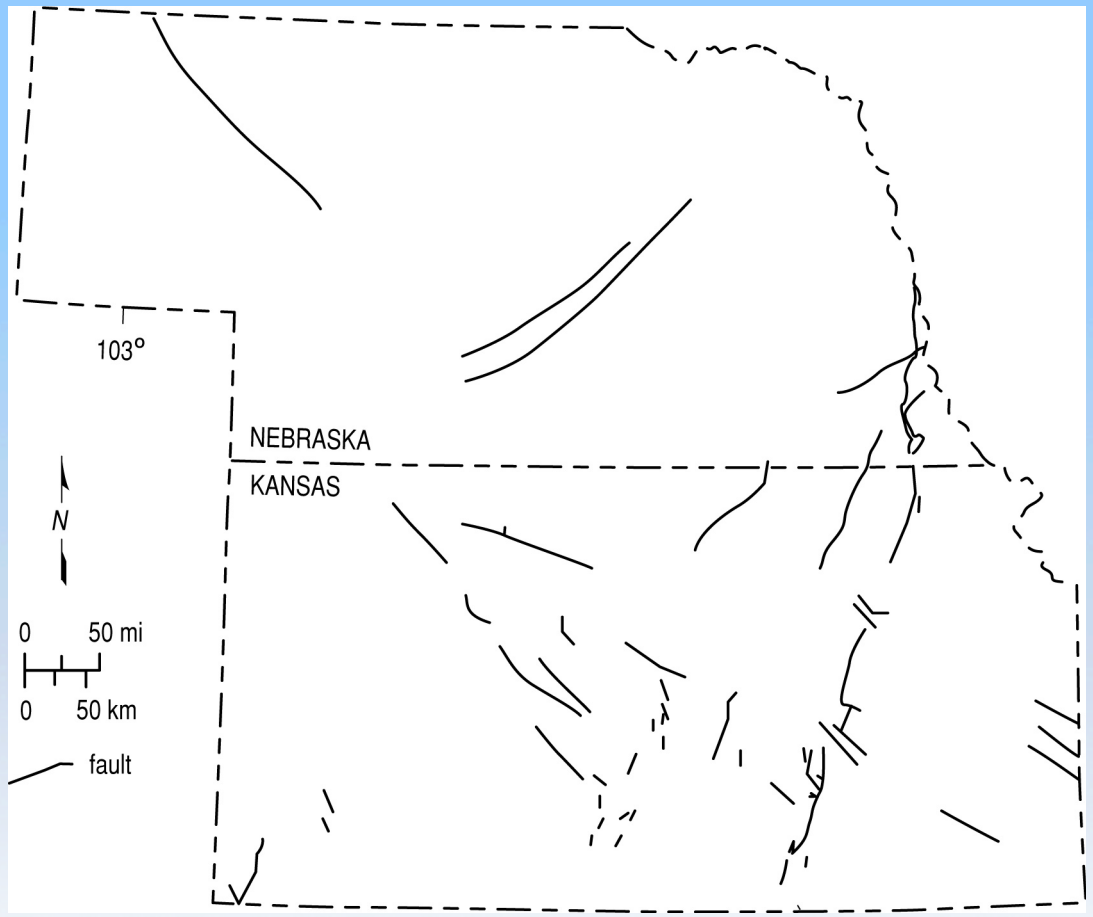
Overview

- Geology
- Historical earthquakes
- Microearthquake studies
  - Kansas-Nebraska Network
  - Rooks County
  - Sleepy Hollow
- Proposed Kansas Network
- Locating Earthquakes

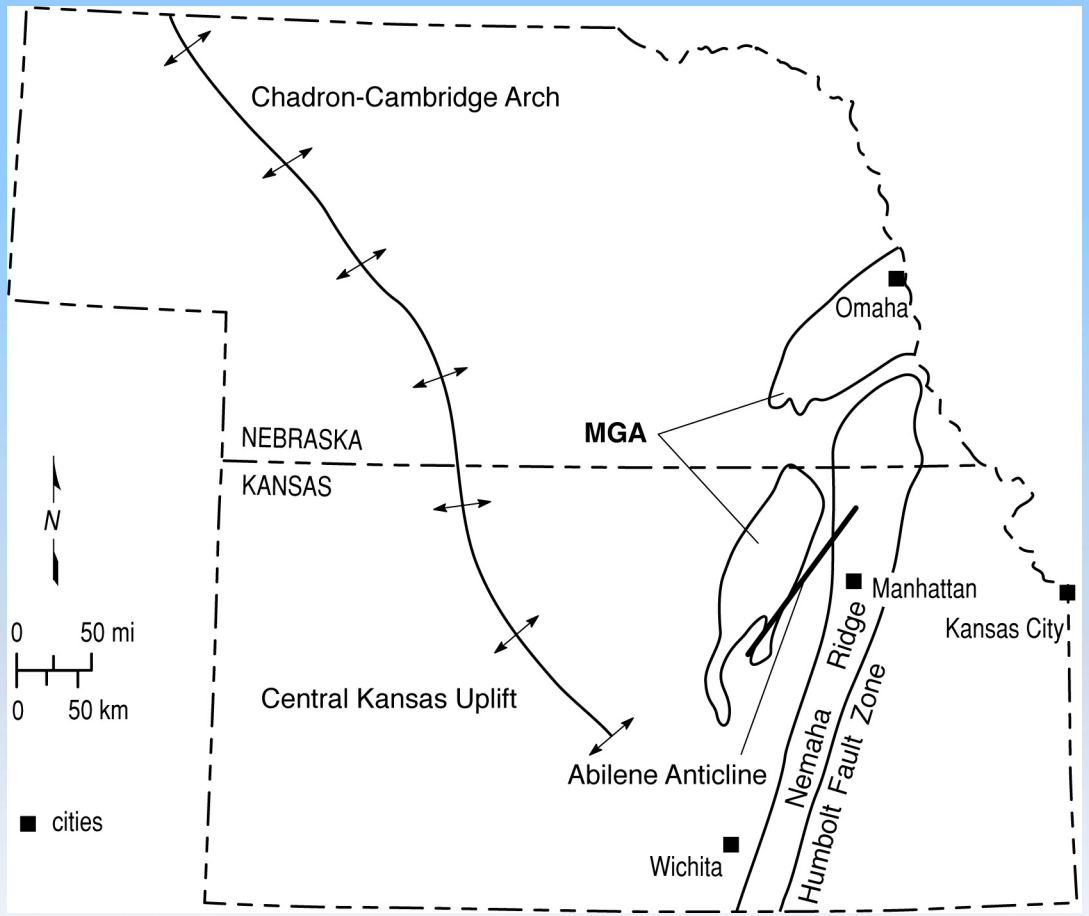
Mapped Basement Faults



Key Features:

- Humboldt Fault Zone
- Central NE faults

Major Midcontinent Features



Major tectonic structures:

- Nemaha Ridge
- Midcontinent Geophysical Anomaly (MGA)
- Central Kansas Uplift

Historical Background

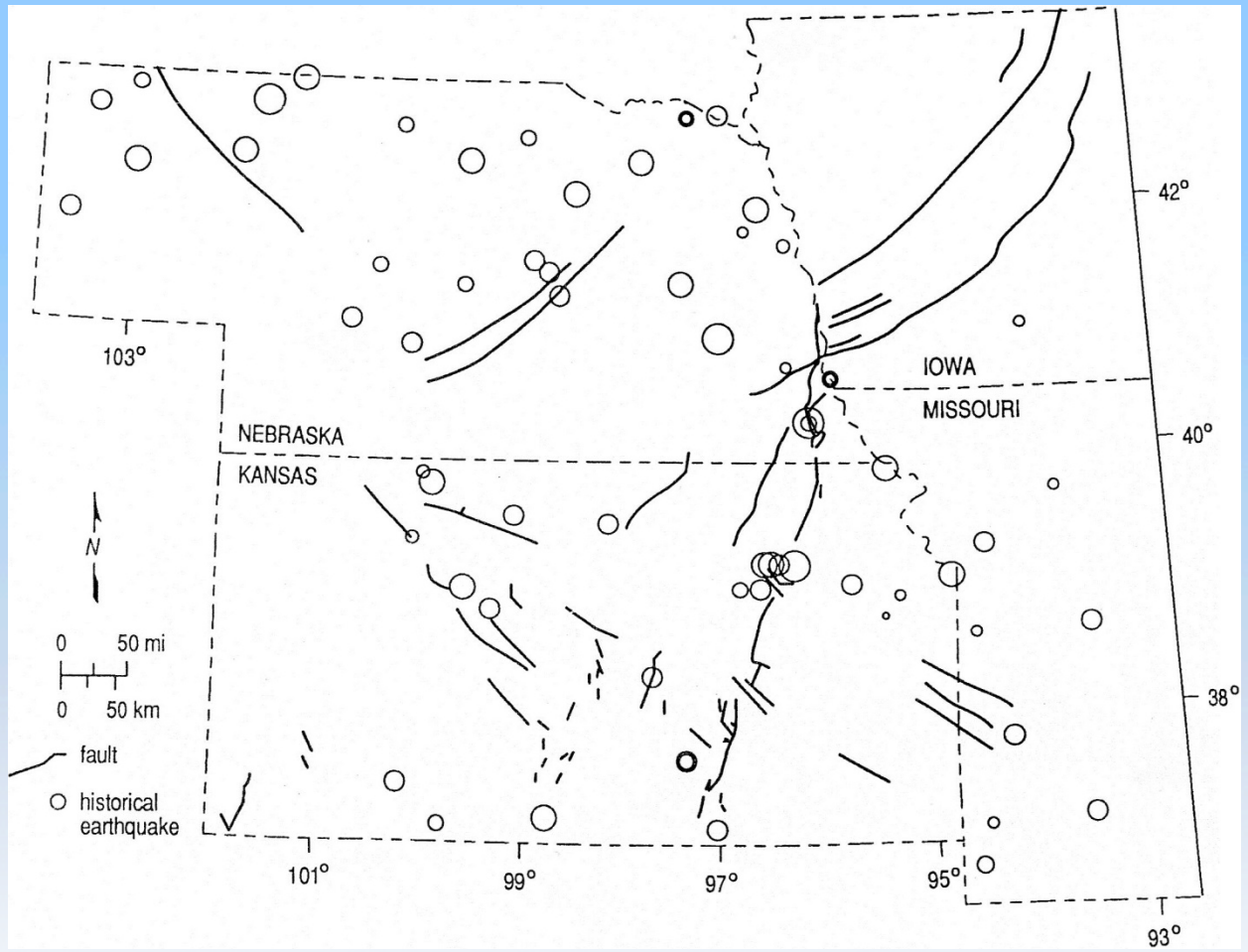
Relatively low historic seismicity

30 felt earthquakes reported 1867-1977

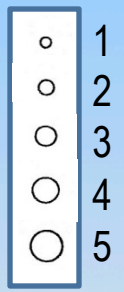
Mainly attributed to:

- Nemaha Ridge (buried Precambrian granite uplift)
- Humboldt Fault (eastern boundary of Nemaha Ridge)
- Midcontinent Geophysical Anomaly (zone of late Precambrian rifting)

Historical Felt Earthquakes

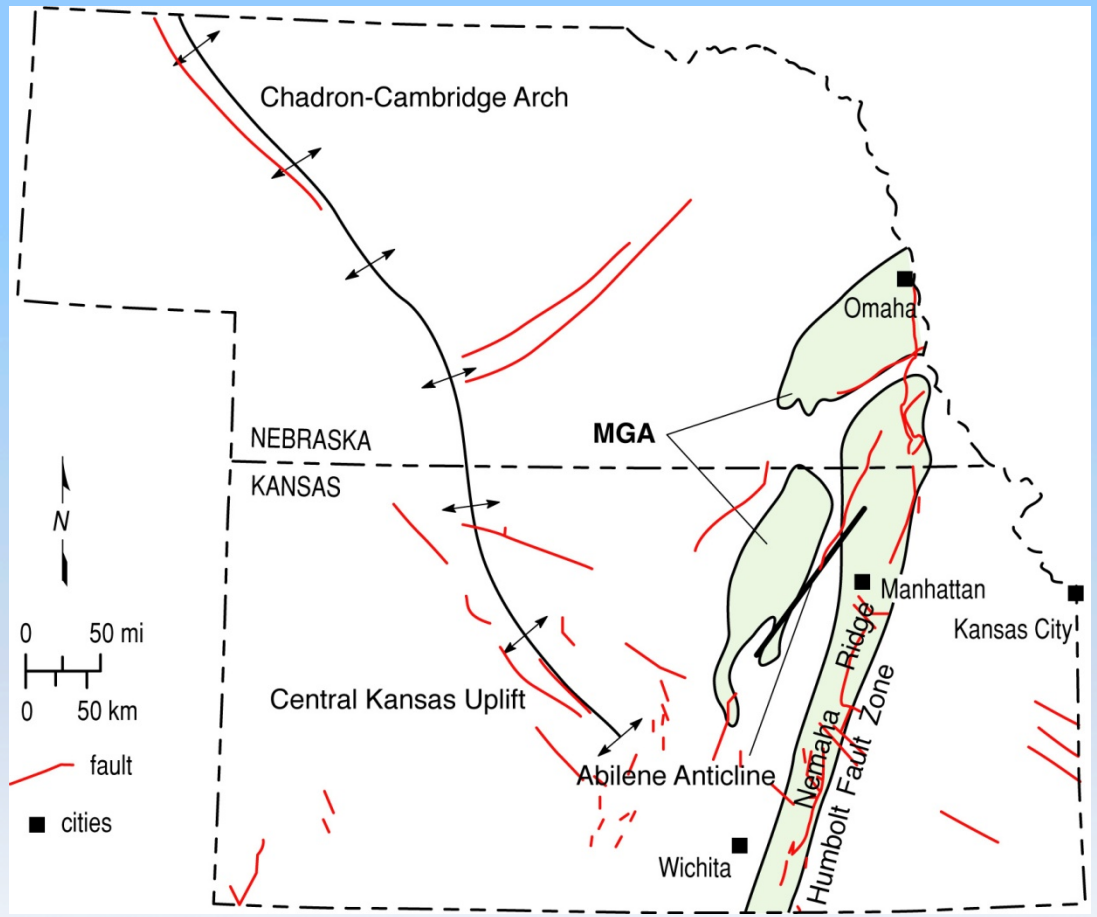


Modified Mercalli Scale



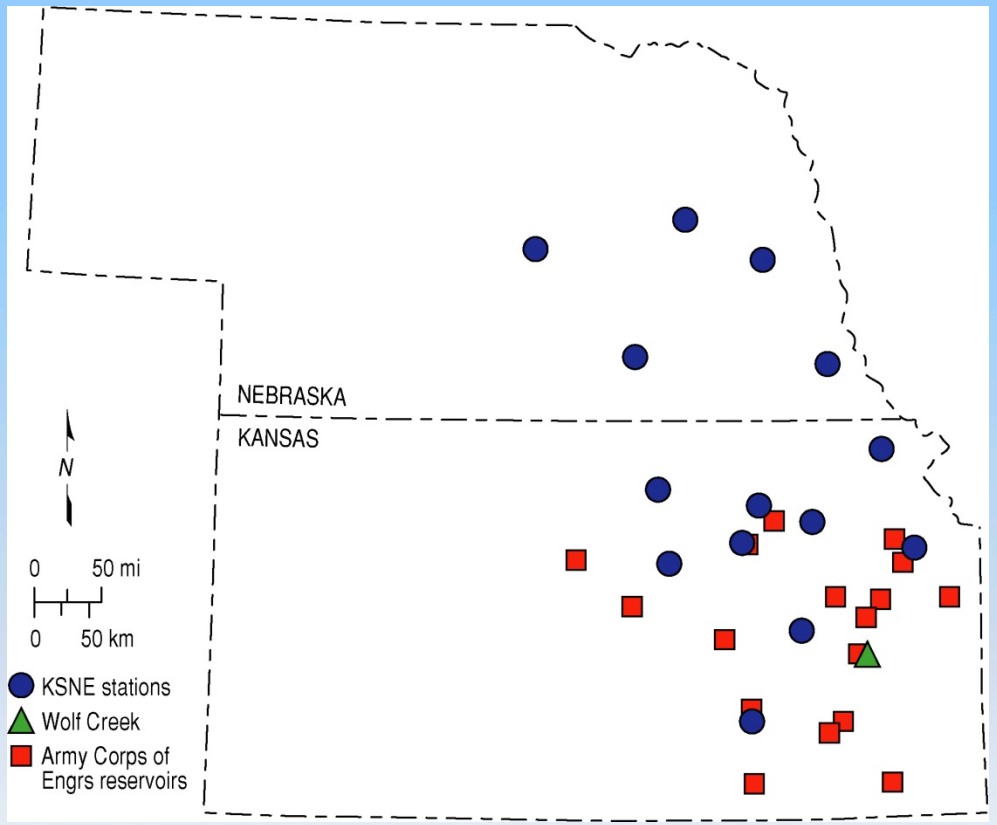
Regional historic earthquakes

KS-NE Network



NRC & USACE Sponsored KS-NE Network

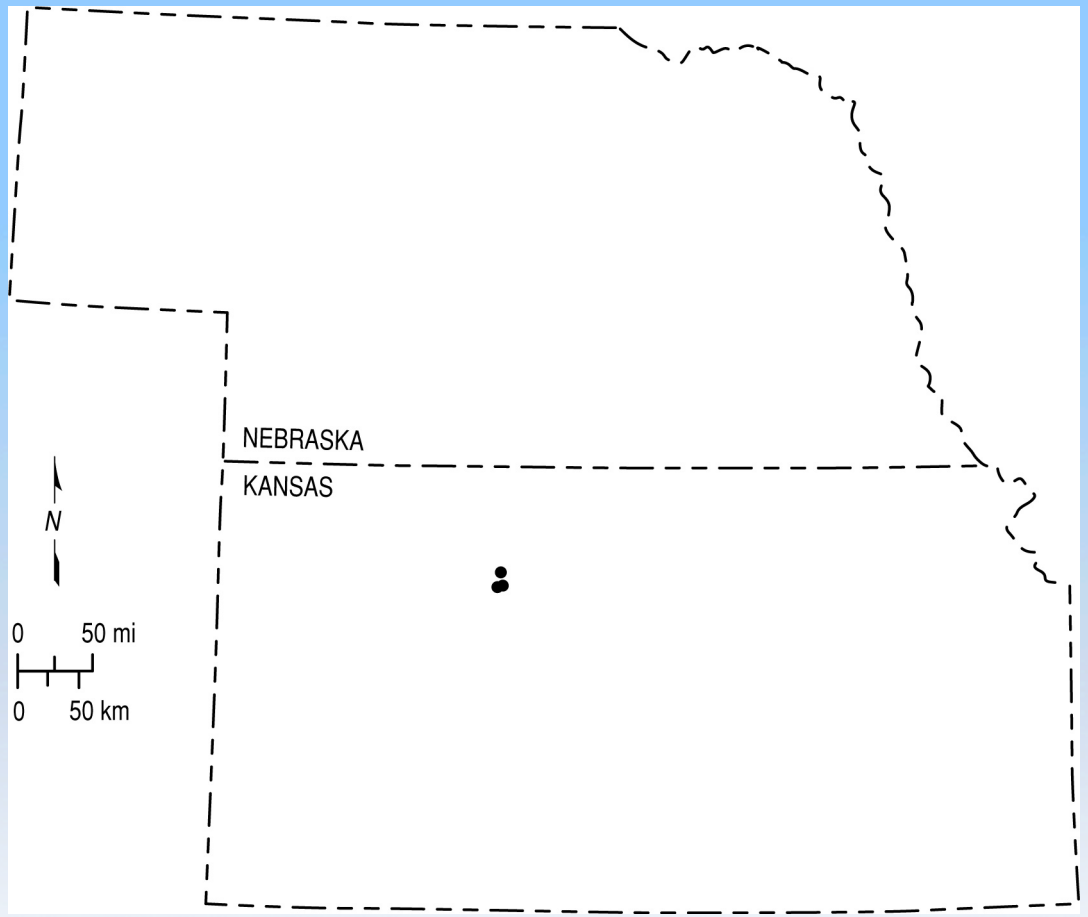
- Twelve year project (1977-1989) to study earthquakes and seismic risk
- Relate earthquakes to specific fault zones or tectonic features
- Estimate relative seismicity of various regions



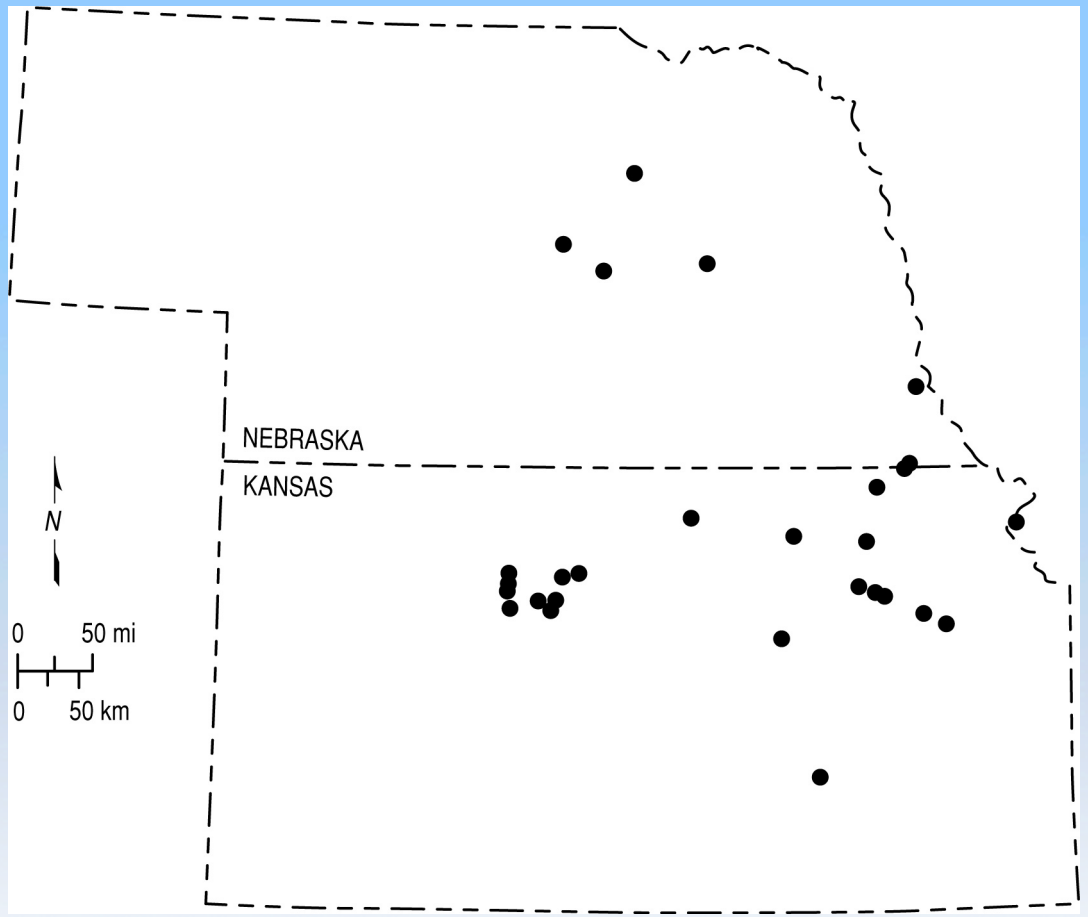
KS-NE Network 1977-1989

- Located 264 earthquakes
  - magnitude from 0.5 to 4.0
- Identified four distinct geologic trends:
  - Humboldt Fault Zone
  - Northwest flank of the MGA
  - Central Kansas Uplift
  - Central NE faults (two parallel faults, no named structure)

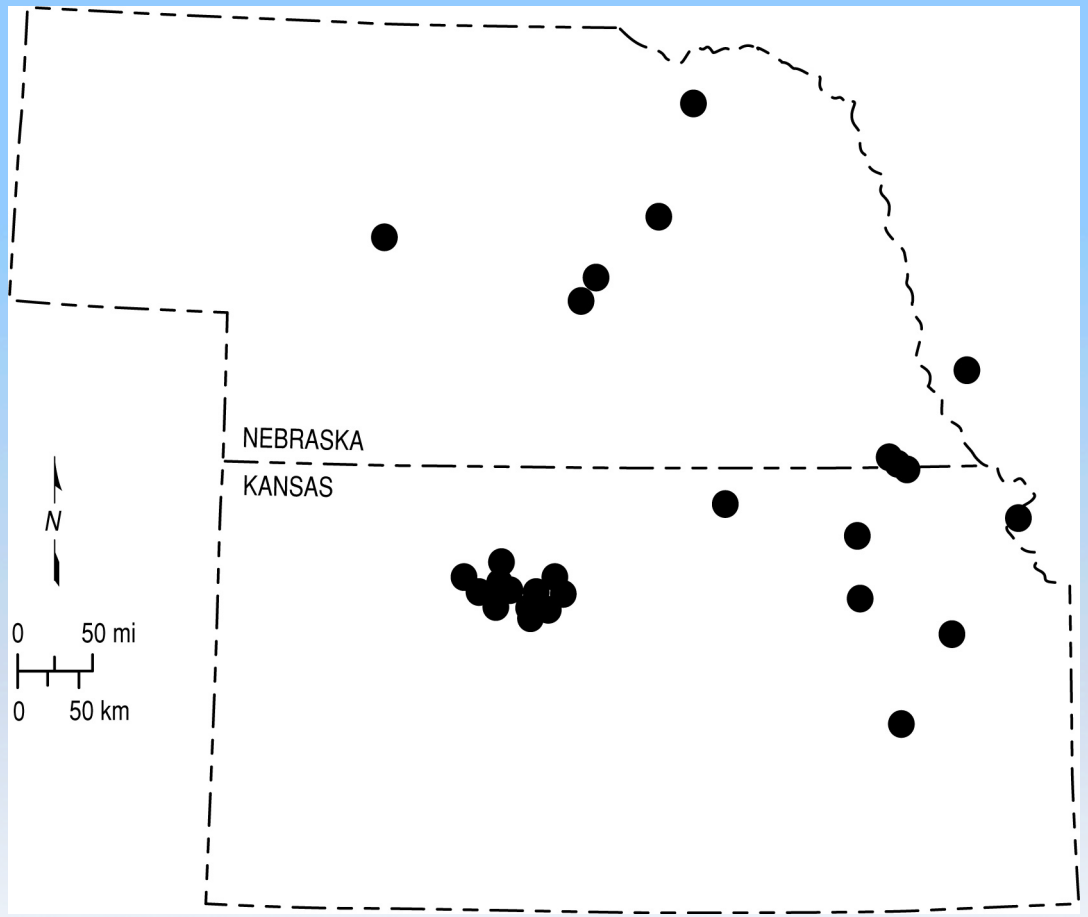
KS-NE Network: M<1



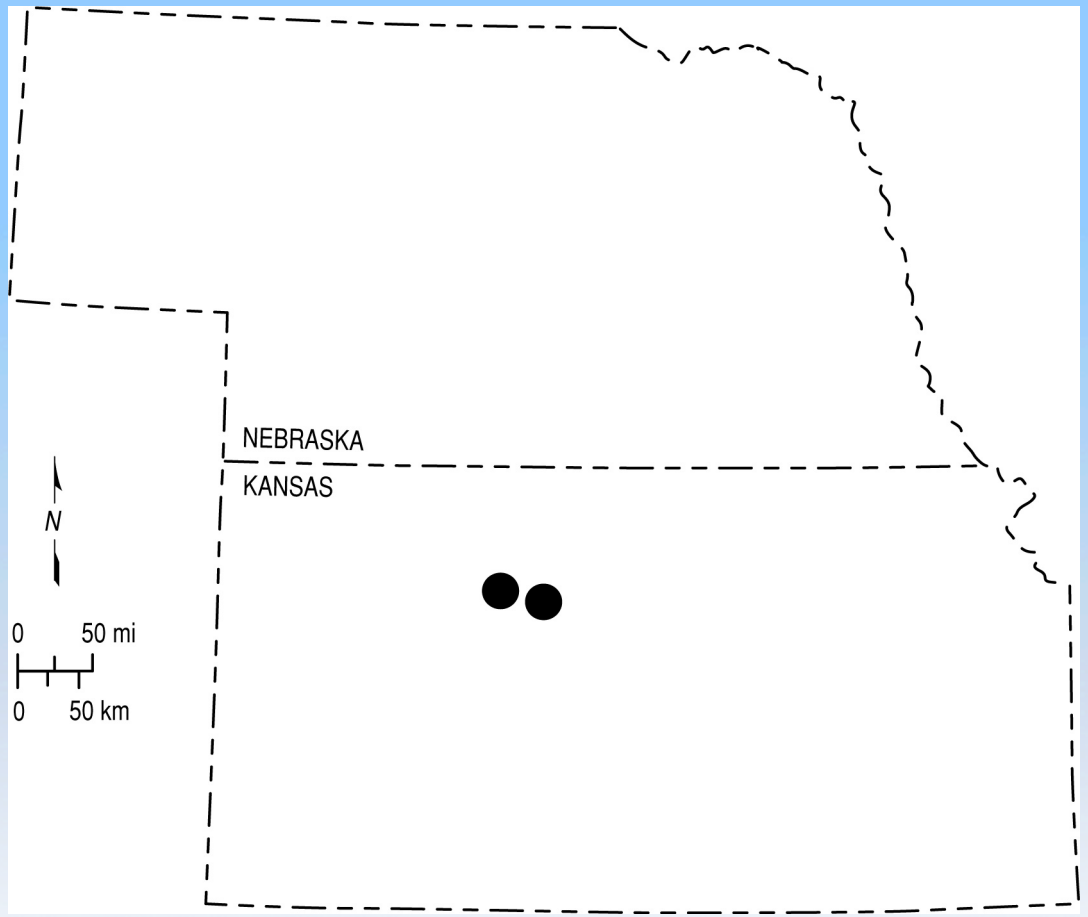
KS-NE Network: M=1-2



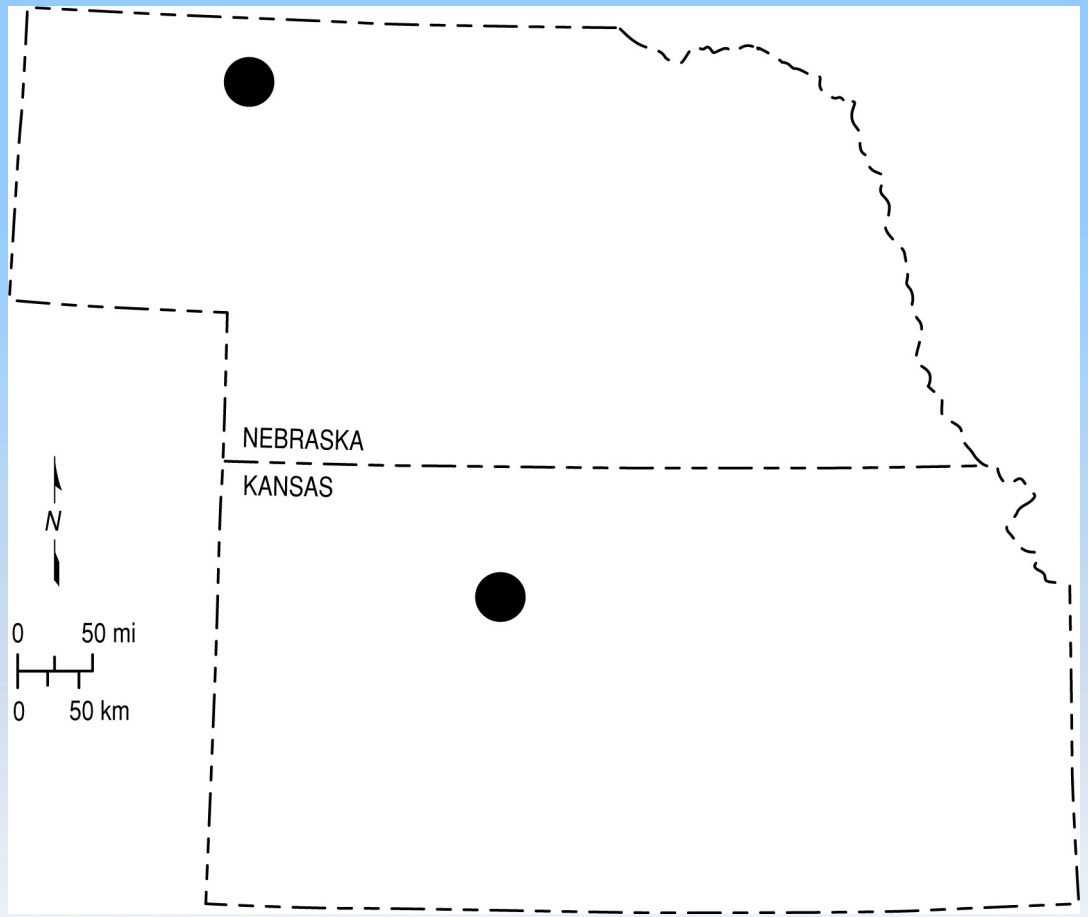
KS-NE Network: M=2-3



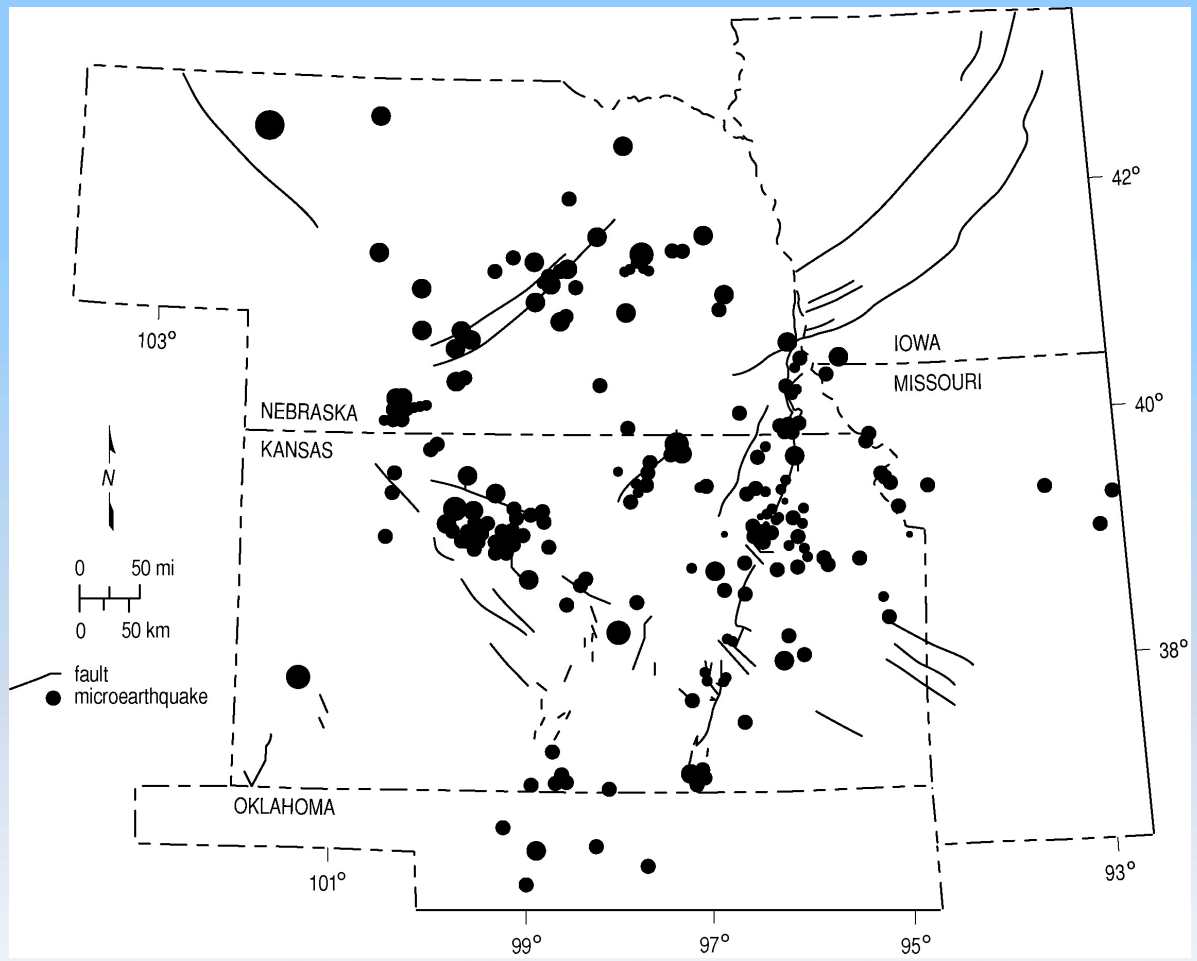
KS-NE Network: M=3-4



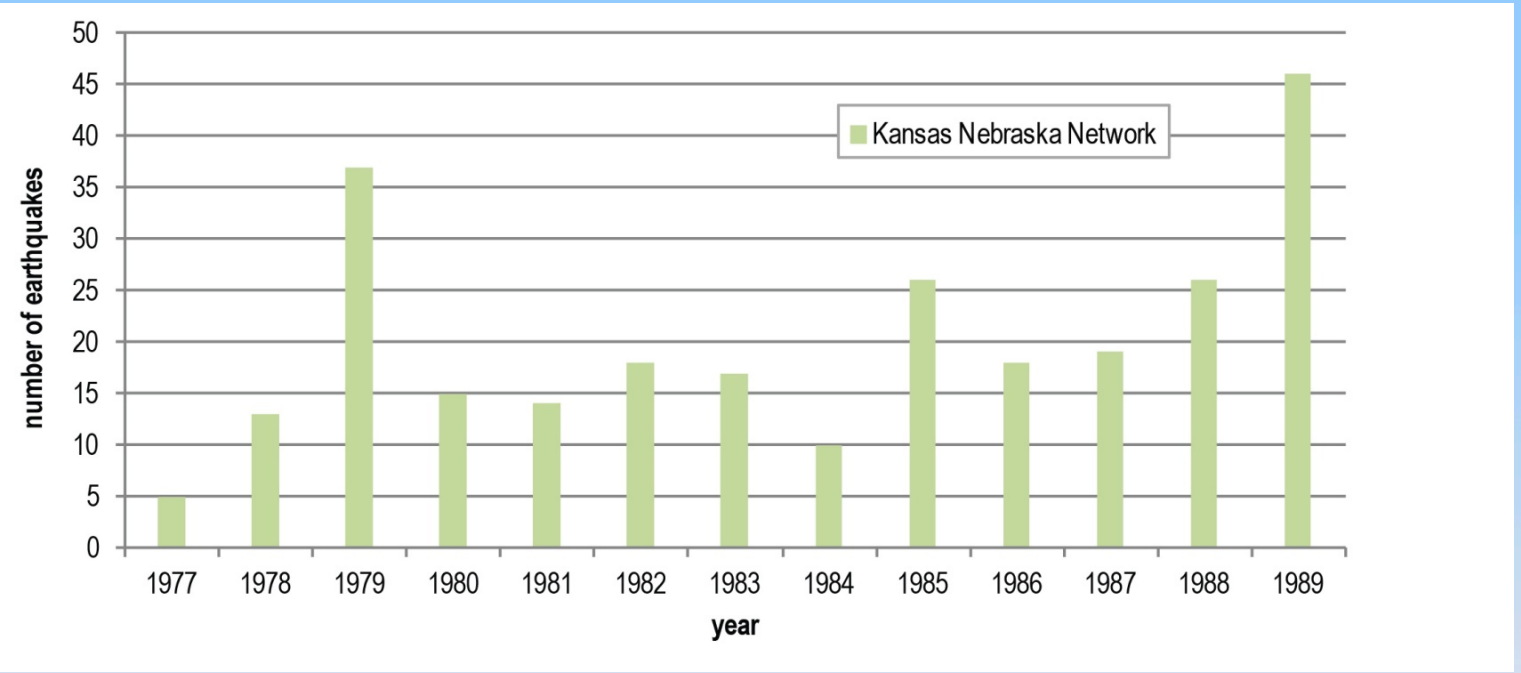
KS-NE Network: M=4-5



KS-NE Network

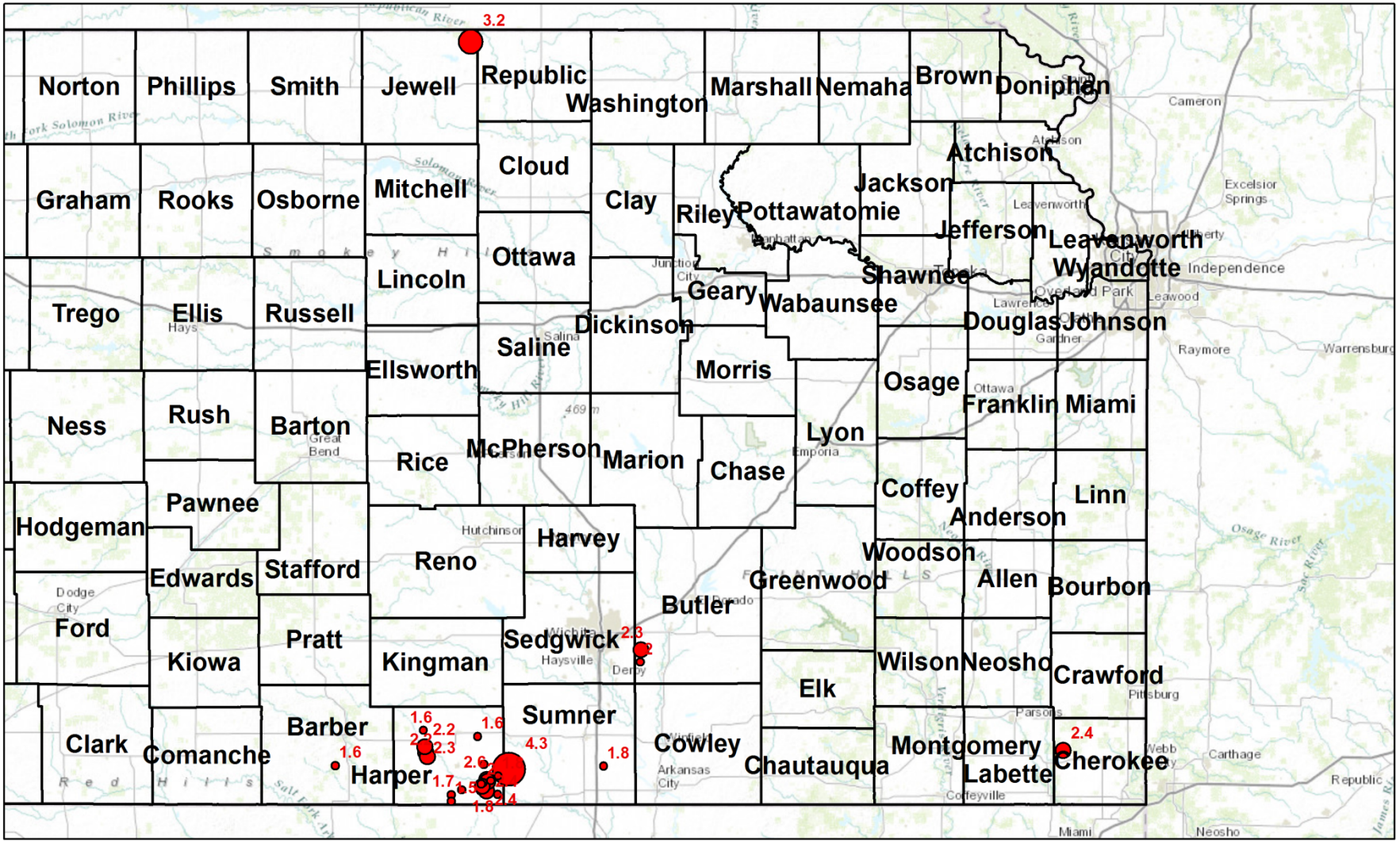


KS-NE Network



Earthquake Activity - 2013

PRELIMINARY

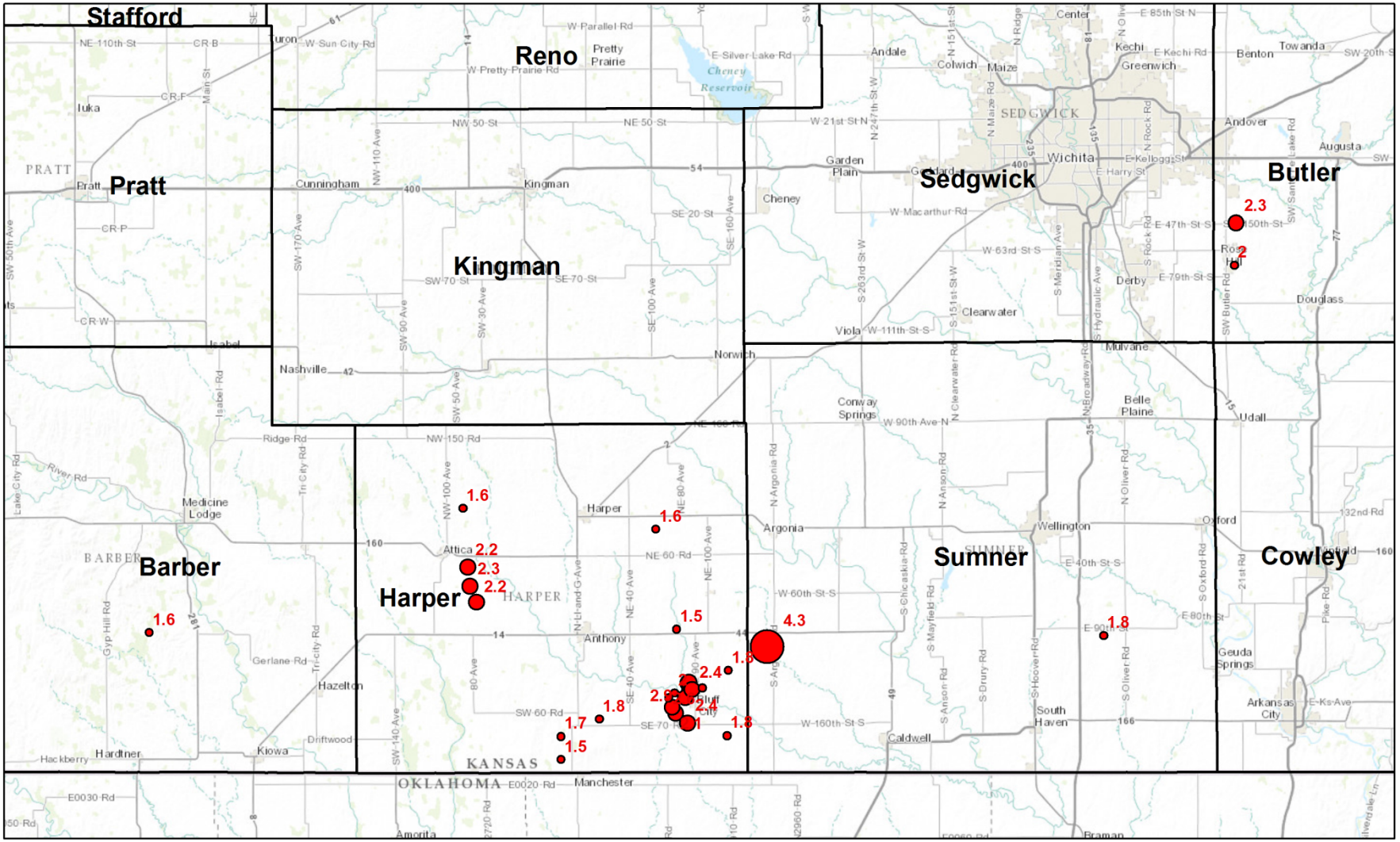


Kansas Geological Survey
Data from Oklahoma Geological Survey, USGS
18 March 2014

0 20 40 80 Miles

Earthquake Activity, South Central Kansas - 2013

PRELIMINARY

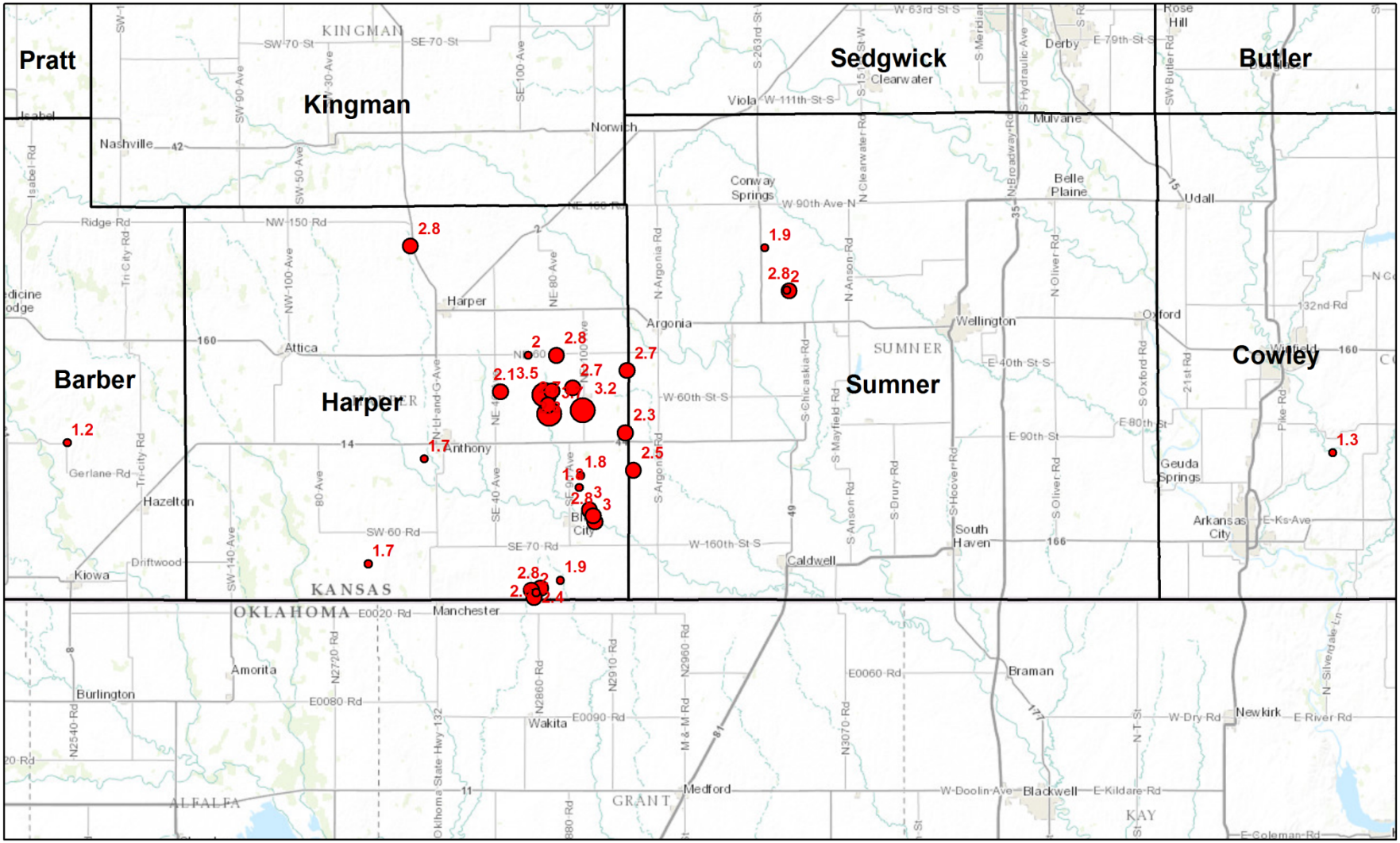


Kansas Geological Survey
Data from Oklahoma Geological Survey, USGS
18 March 2014

0 5 10 20 Miles

Earthquake Activity - 2014

PRELIMINARY

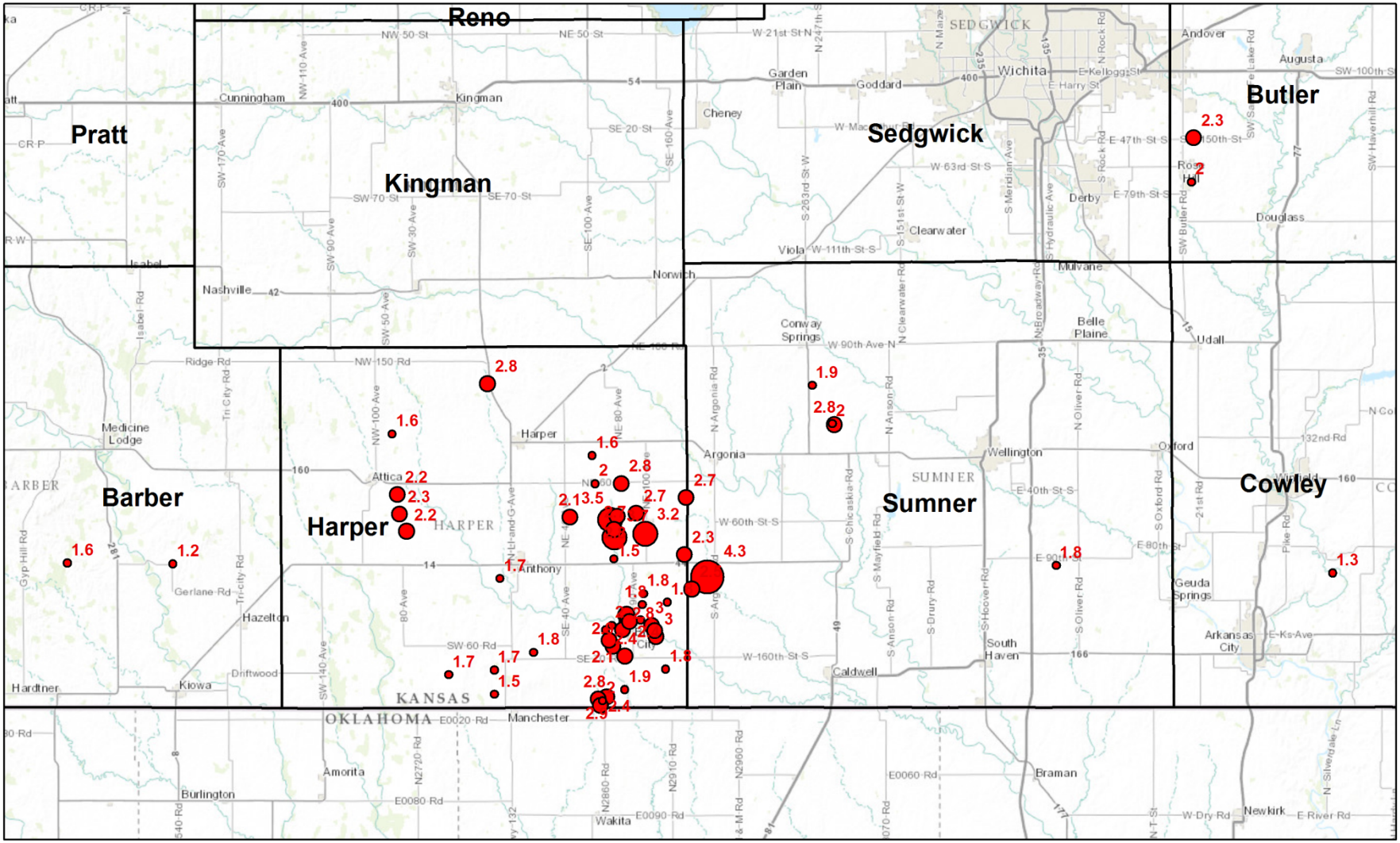


Kansas Geological Survey
Data from Oklahoma Geological Survey, USGS
14 April 2014

0 5 10 20 Miles

Earthquakes 8/1/2013 to 4/15/2014

PRELIMINARY



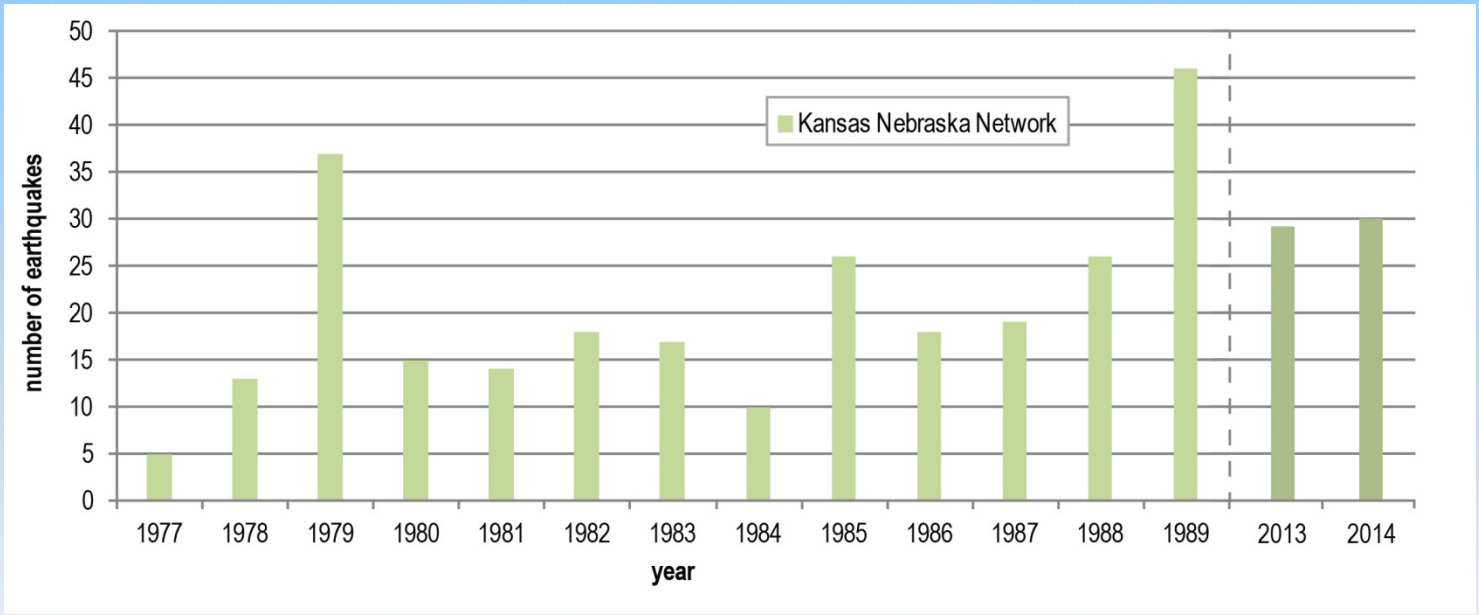
Kansas Geological Survey
Data from Oklahoma Geological Survey, USGS
15 April 2014

0 5 10 20 Miles

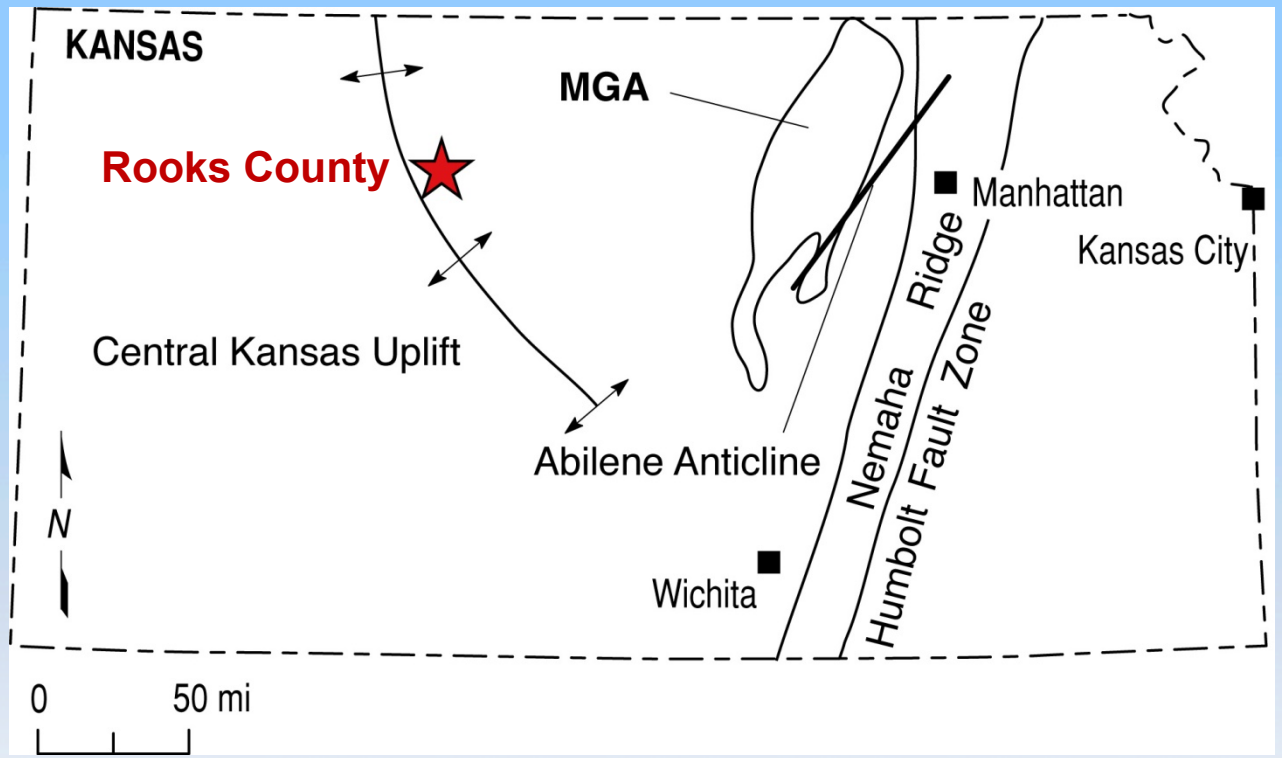
Earthquake Numbers

1977-1989 KS-NE Network

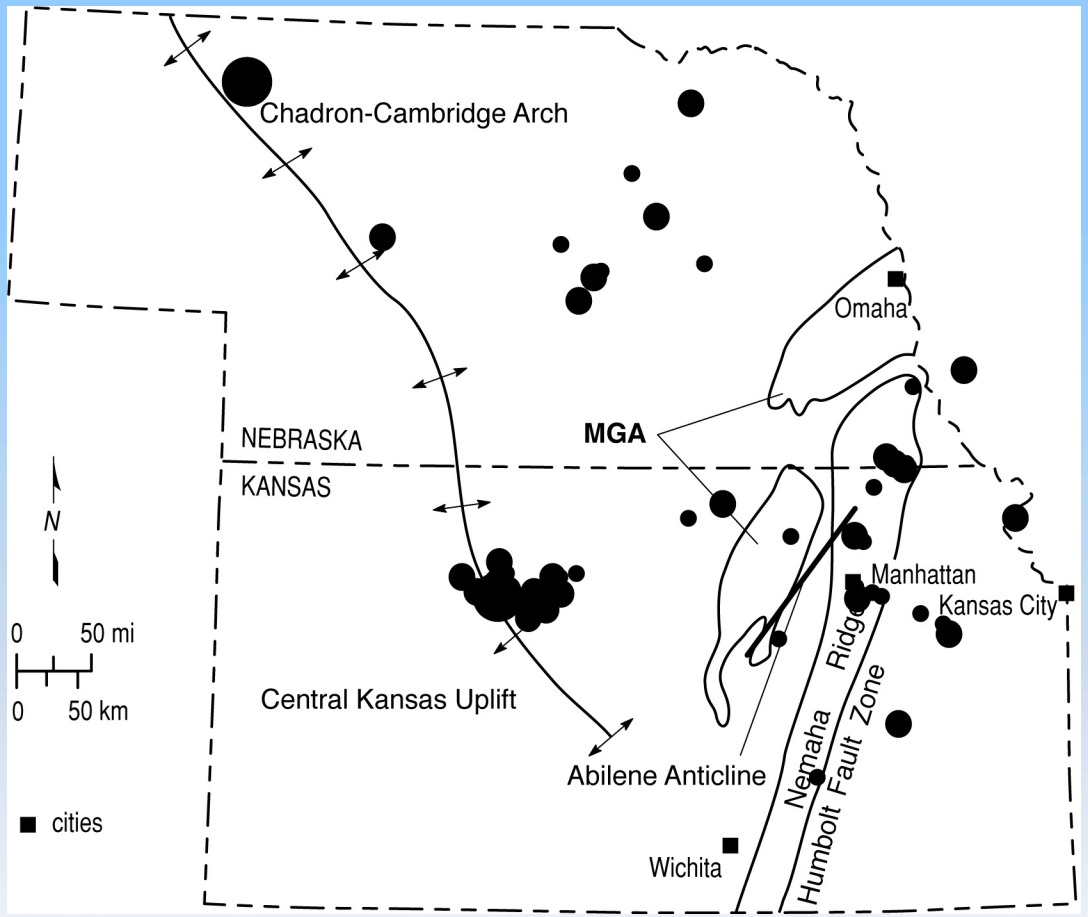
2013-2014 OGS-USGS recording



Rooks County, KS



KS-NE Network



Rooks County, KS

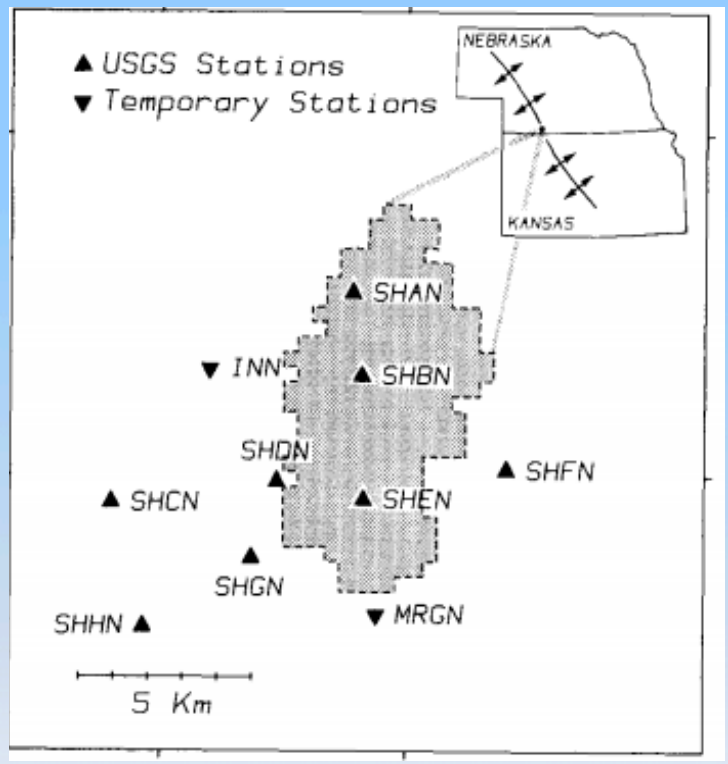
- August 10-19: portable 7-station array deployed
  - Approximately 60 events recorded
  - Zone of seismicity
    - Within Marcotte Oil field
    - Located along steeply dipping 1 mile long zone
    - Extends from approximately ¾-1½ mile deep in basement rock
  - One injection well coincident with the most active part
- Study concluded these earthquakes were possibly induced
  - Coincident disposal well
  - Change in poor pressure
  - “Swarmy” nature of seismicity
  - Low level of historic earthquake activity

Rooks County, KS

- Background
  - Historically low seismicity
  - Prior to 1989, only 3 historic earthquakes (M > 4) reported in western Kansas
  - Marcotte Oil Field
    - Production began in 1950's
    - Multiple class II brine injection wells, associated with increased pore pressure
- June to August, 1989: Sequence of many felt earthquakes (largest M = 4) reported near Palco

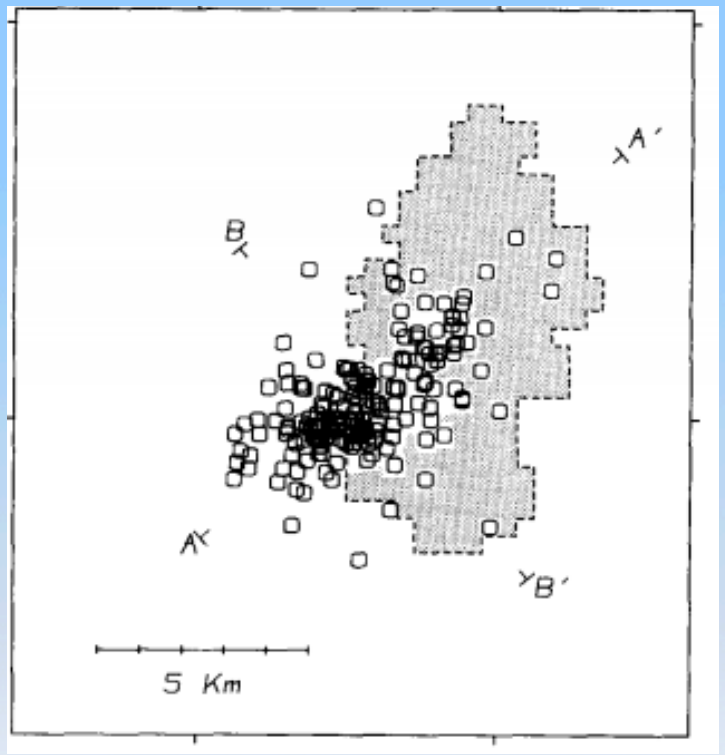
Sleepy Hollow Oil Field

- Geologic background
  - Near intersection of Central KS Uplift and 2 central NE faults
  - Tectonically active in recent past w/ continued subtle uplift
  - Most productive NE oil field
  - ½ to ¾ mile deep
- EOR began in 1966
  - Water injection wells mainly in the periphery of the field
  - Numerous felt earthquakes from 1977



Sleepy Hollow Oil Field

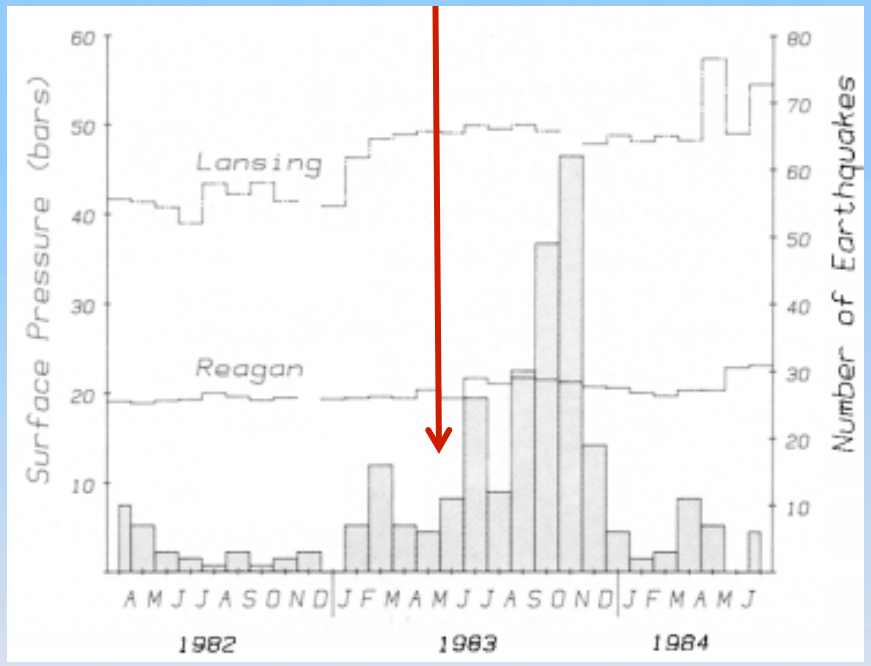
- Seismic monitoring
  - Funded by USGS 1982-1984
  - 8 permanent stations, 2 portable stations
- 311 microearthquakes detected near the oil field
  - 176 located
    - magnitude -1.4 to 1.8
    - 50 in reservoir
    - 126 in granite basement beneath reservoir



Sleepy Hollow Oil Field

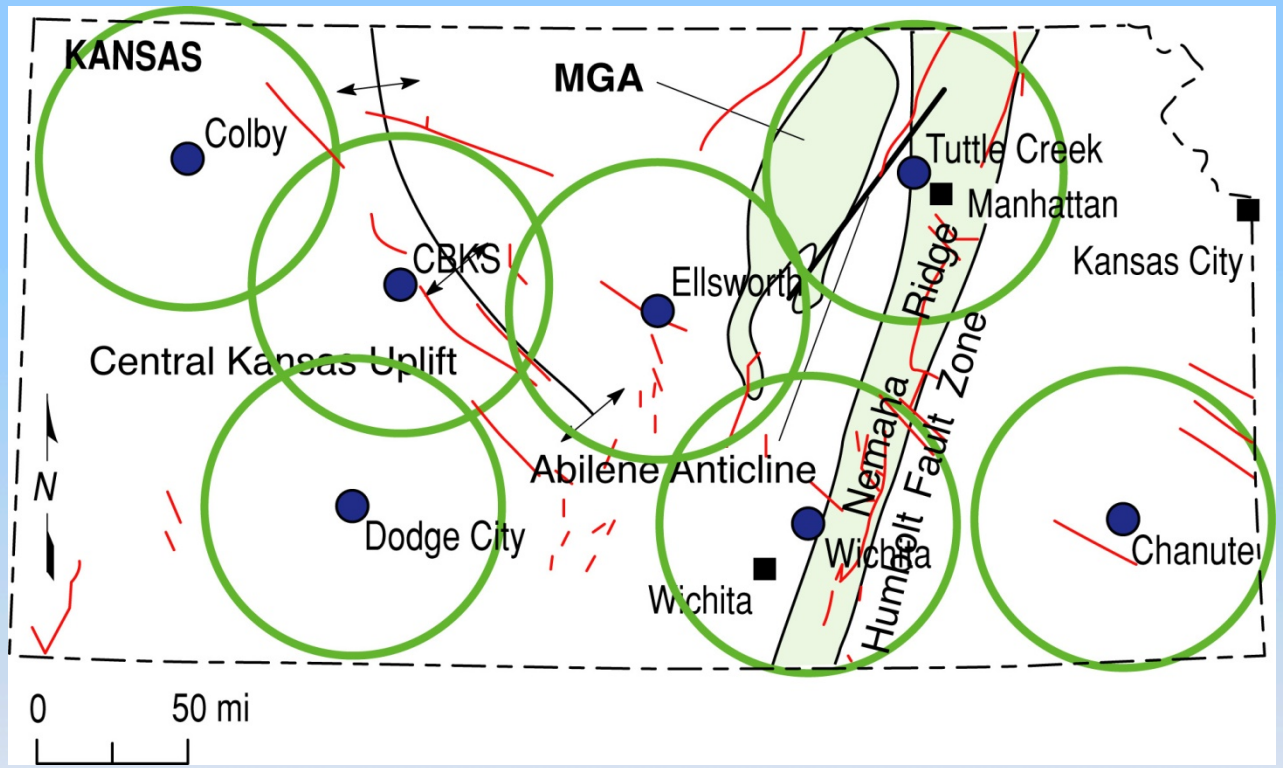
- January 1983: 10 new injection wells in field
  - 6mo increased seismic activity following well installation
  - Increase near new wells
  - Many earthquakes in the granite basement, unlikely injected fluids reached these depths
- Conclusions:
  - Geologic evidence suggests earthquakes may have tectonic origin
  - Earthquakes may be related to production activity

10 new fluid injection wells installed



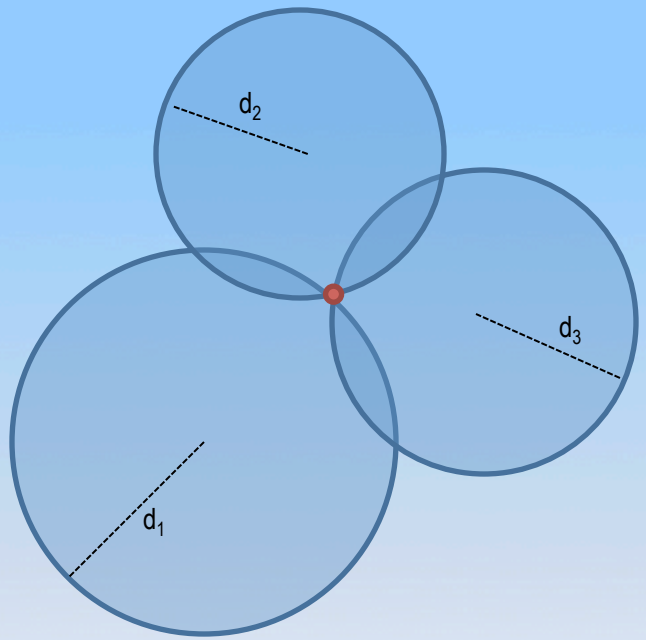
increased seismic activity

Proposed Kansas Network



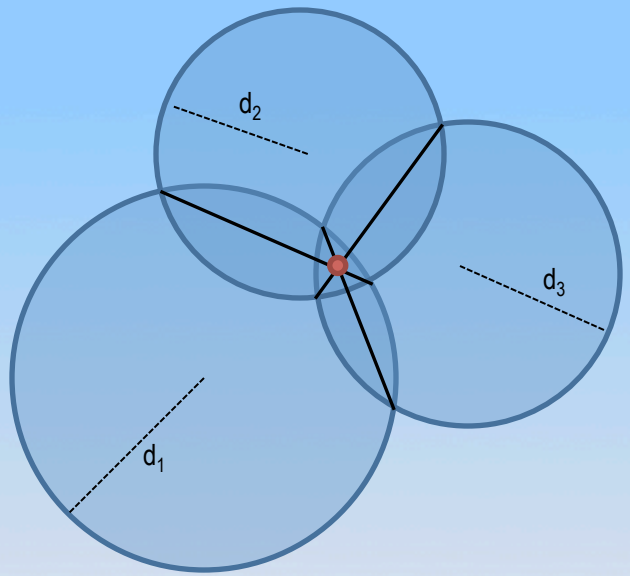
Earthquakes don't occur where there is no instrumentation—paraphrased from comment by Randy Keller—Director OGS

Locating Events: Triangulation



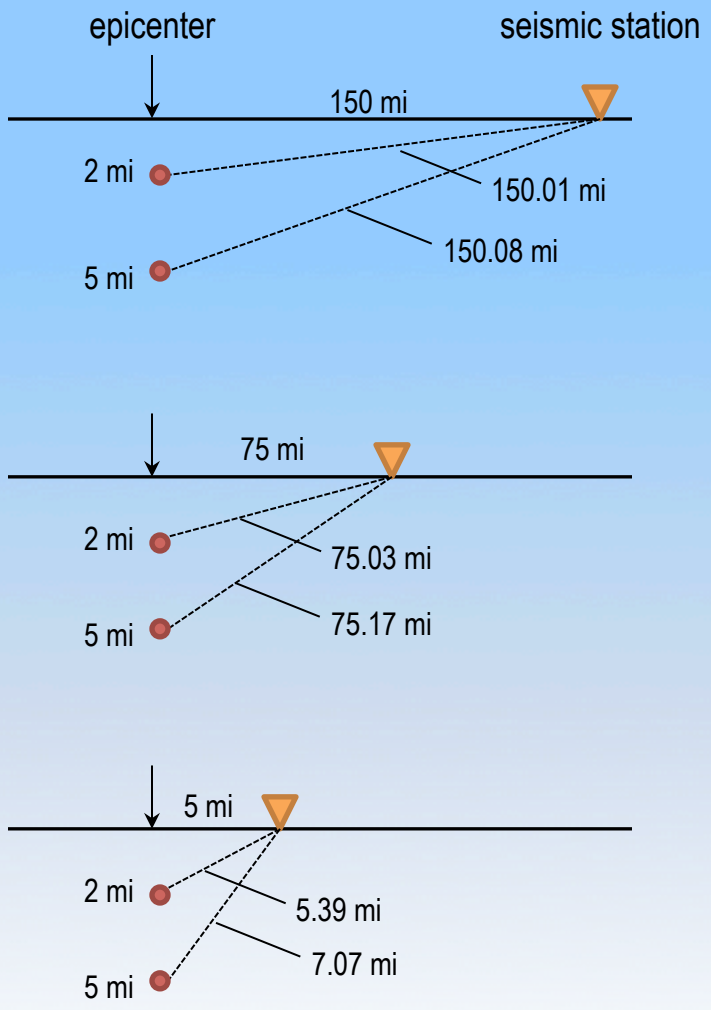
- Requires ≥ 3 stations
- Distance *d* of the epicenter is estimated for each station
  - Determined from arrival time of P- and S-waves
- A circle with radius *d* is drawn around each station
- Intersection of three circles is epicenter location

Locating Events: Accuracy



- Circles do not overlap at point
- Uncertainty in surface location:
  - Error in velocity model
  - Number, geometry, and distance of seismic stations
  - Arrival time uncertainty
  - Depth uncertainty
- Location uncertainty reported by the National Earthquake Information Center (USGS) is ~ 6 miles

Depth Determinations



Depth difficult with distant seismic stations

Traveltime difference between an earthquake at 2 mi and an earthquake at 5 mi depth for seismometers at varying distances (for v = 15,000 ft/s):

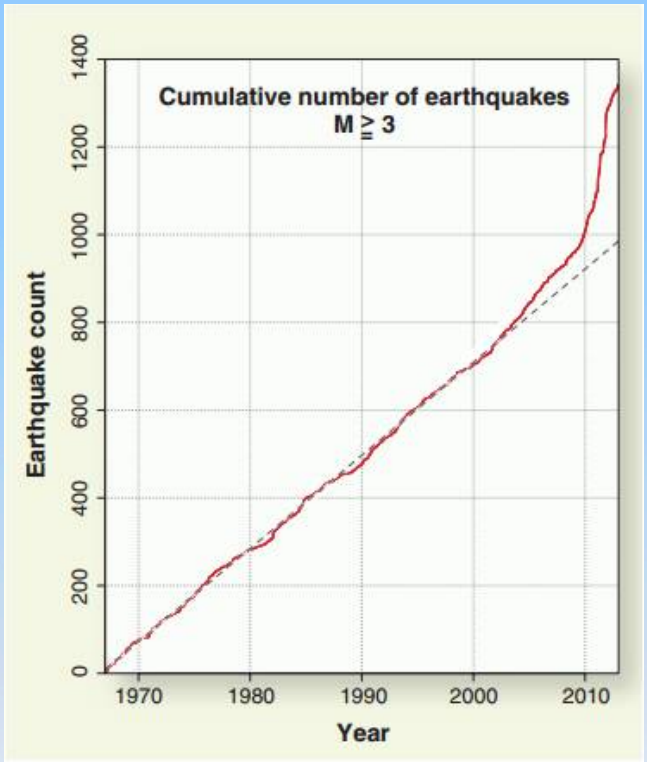
Distance	Time Difference
150 mi	0.02 s
75 mi	0.05 s
5 mi	0.59 s

Rule of thumb: at least a few stations should be within a surface distance of 2x depth

- This is often not possible; therefore, depth is fixed (based on known geology)
- Highlights the need for regional network of stations and small, portable array

Induced Seismicity

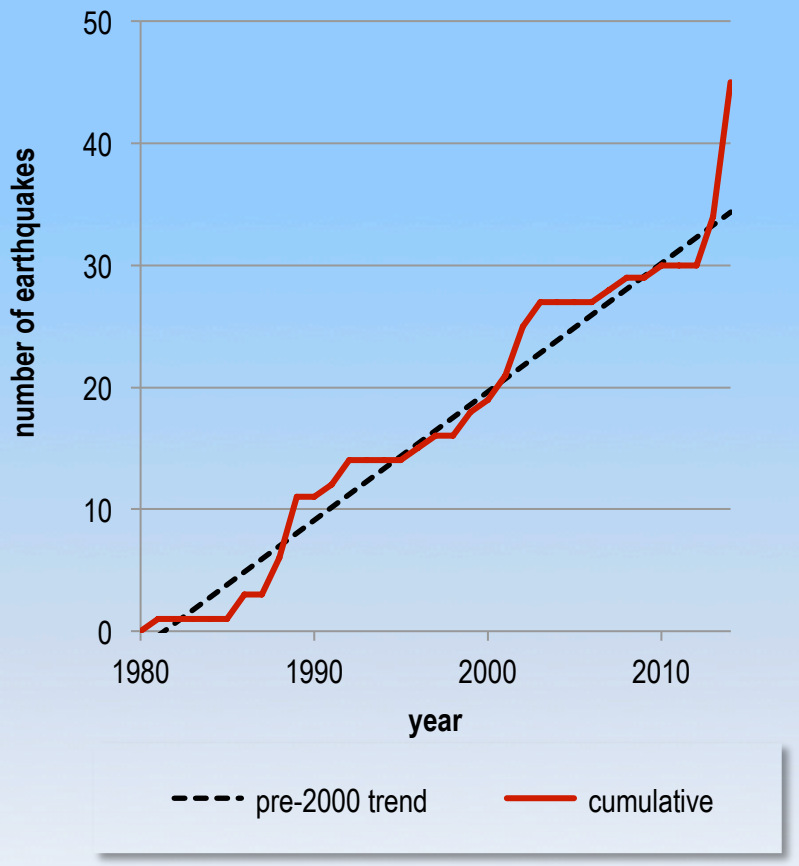
US trend



- From “Injection Induced Earthquakes” (Science)
- Increase in Central and eastern US earthquakes statistically significant
- Author attributes the increase to induced seismicity
- Suggest seismic monitoring to mitigate risk

Induced Seismicity

KS Trend



- Earthquake trend in Kansas
- Observations are consistent with general Midwest trend
- Network of permanent seismographs proposed to monitor seismicity in Kansas

KS-NE Network